清華大學
Tsinghua University

Prospects and Progress of the Jinping Neutrino Experiment

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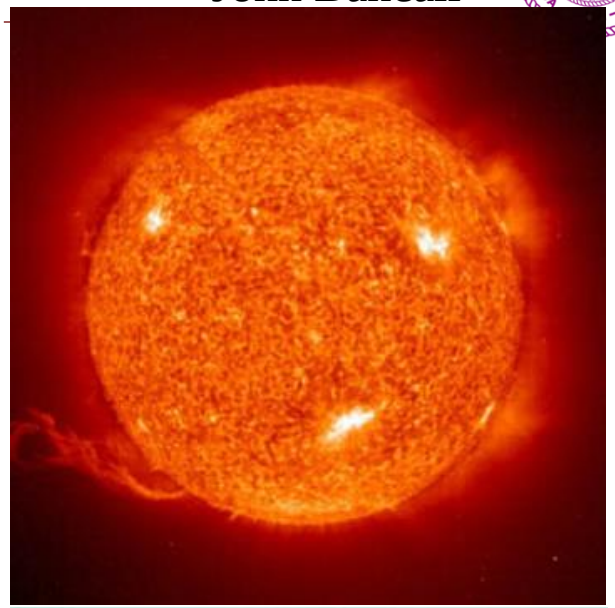
Contents

- Motivation
- Jinping laboratory
- Jinping Neutrino Experiment Proposal
- R&D effort
  Slow LS, Reflector, SST, One-ton Prototype …
- Idea: Measure K-40 and Mantle Geoneutrinos
- Conclusion

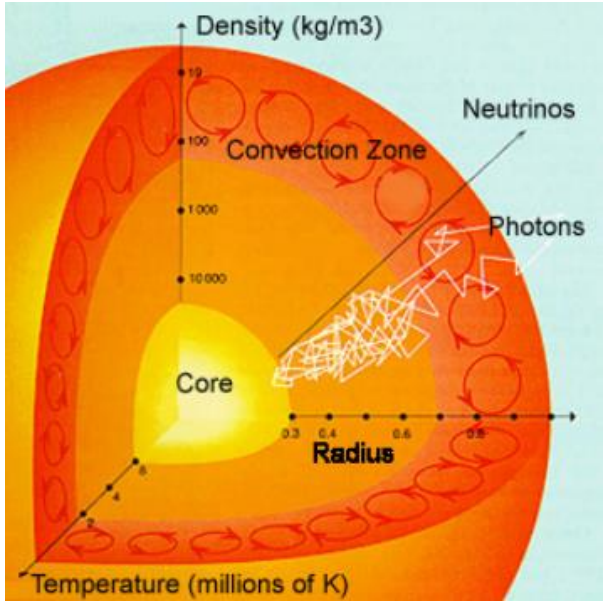
Interests in solar, supernova, and geo neutrinos

Evolution of the Sun – Solar Model

John Bahcall

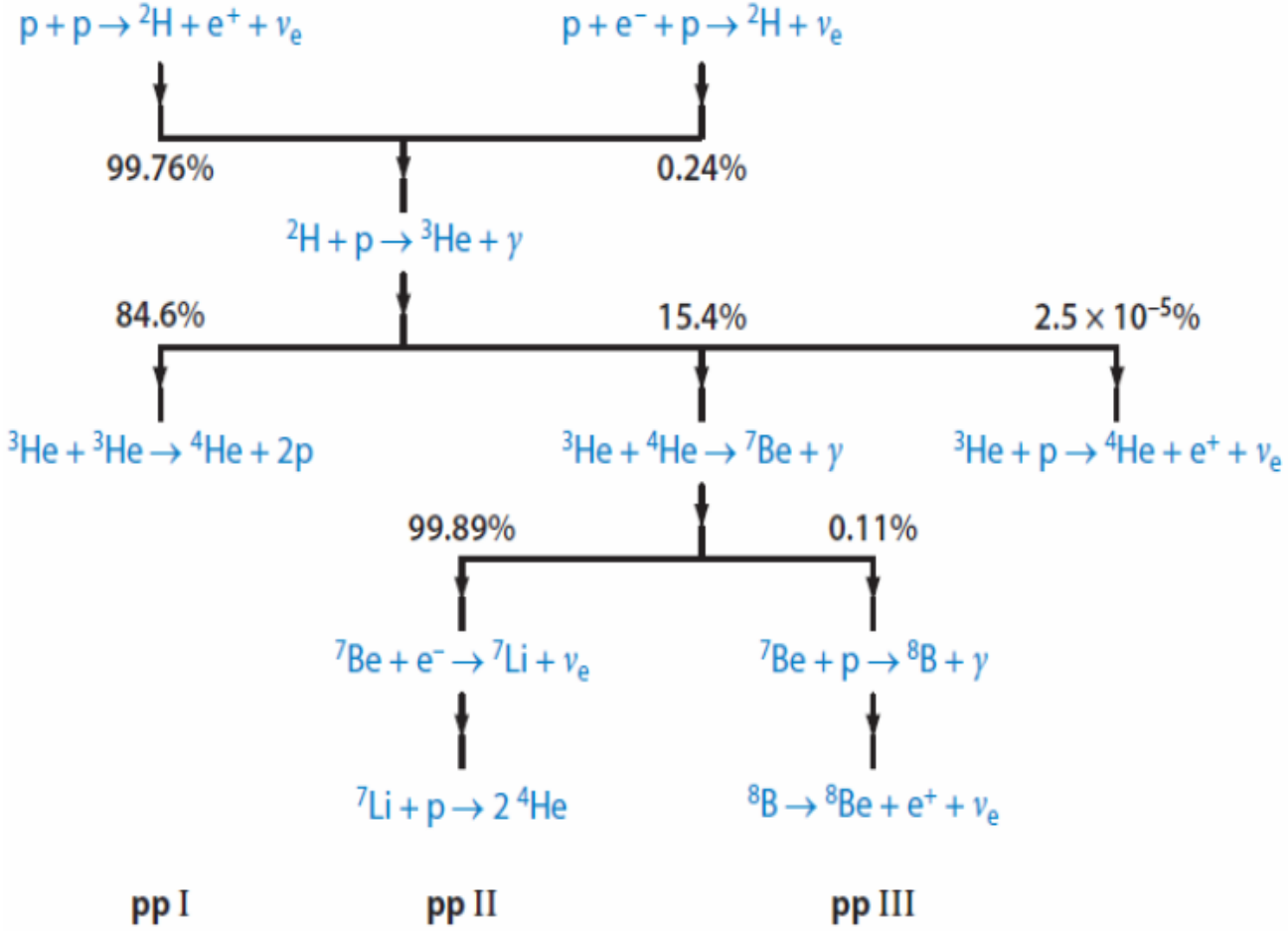


1. **Fueling mechanism：**
   pp chain
   CNO cycle (mainly in high mass stars)
2. **Energy transmission：**
   Radiation (opacity) inner
   convection outer
3. **Equation: Balance of the gravity, radiation, and particle pressure**
4. **Initial conditions**
   Abundance of H, He, metal elements
   Radius, age, mass …
   Assume: Initial metal fraction = surface fraction = core fraction

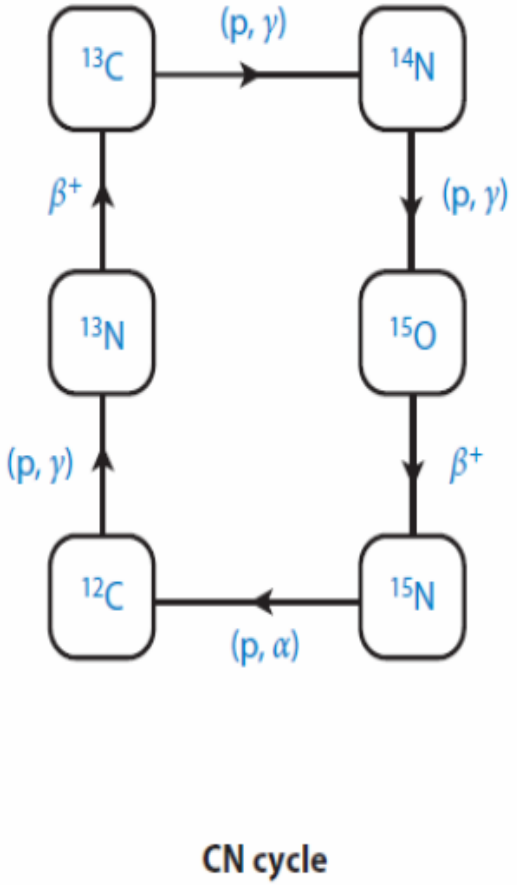


Solar Modal and Neutrino Components

The pp Chain

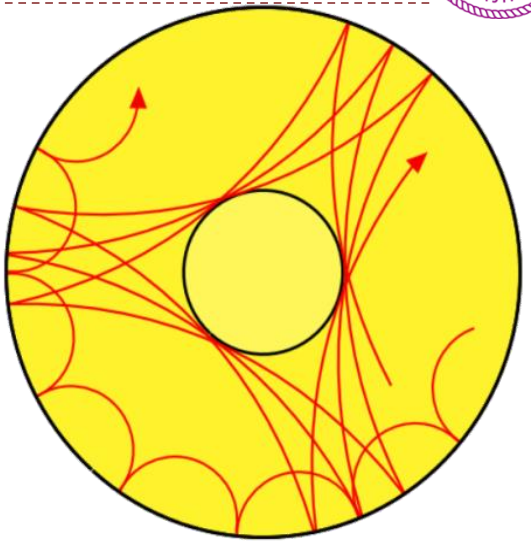


The CNO

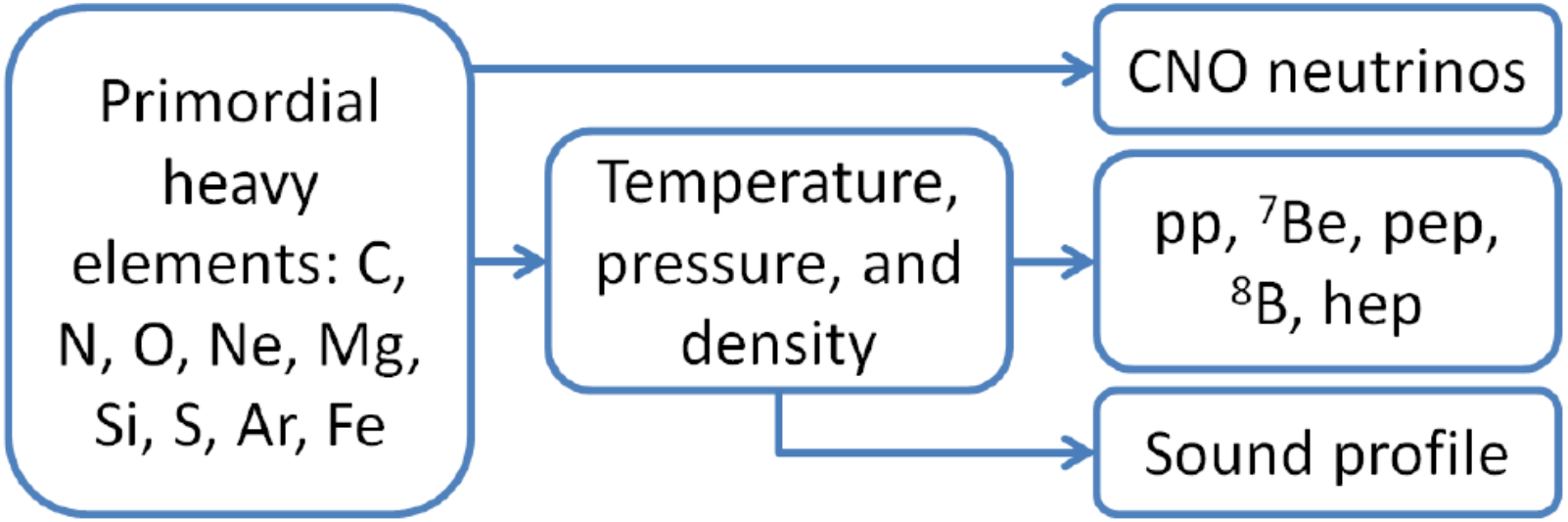


Helioseismology and conflict

Resolve the degeneracy of metallicity and radiation opacity

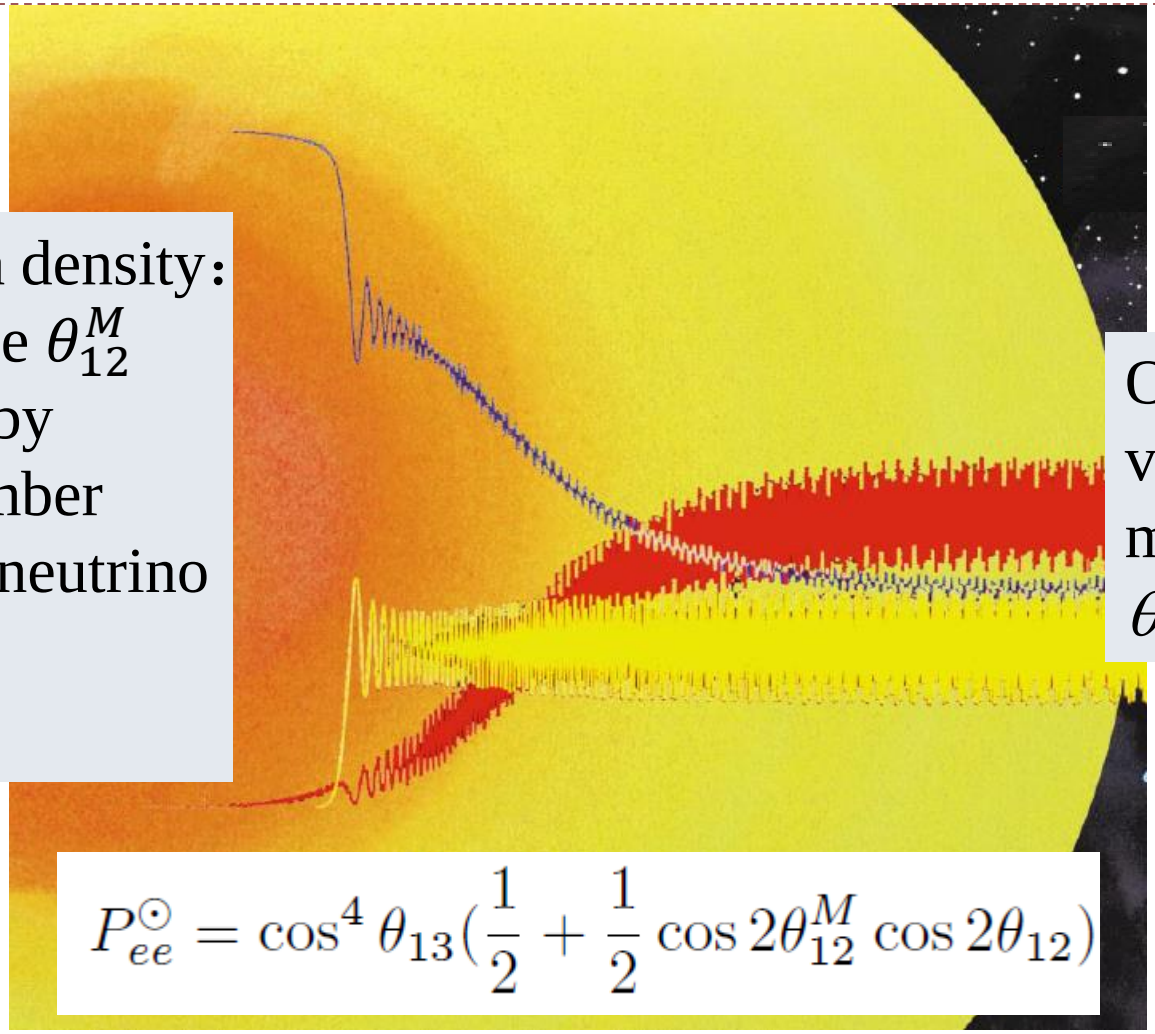


New (better) calculation of
Solar model conflicts with helioseismology measurement: sound speed differ by ~40%



Neutrino oscillation upturn

Center-High density: Mixing angle θ_{12}^{M} determined by electron number density and neutrino energy



Outside: vacuum mixing angle θ_{12}

$$P_{ee}^{\odot} = \cos^4\theta_{13}\left(\frac{1}{2} + \frac{1}{2}\cos 2\theta_{12}^{M}\cos 2\theta_{12}\right)$$

* If going through the Earth, the survival probability will change ~3%

Basic questions of the Sun

The mechanism of solar evolution

- CNO neutrinos not discovered
  1% in the Sun, but major fueling process for high temperature stars
- CNO neutrinos: a direct probe of the core of the Sun
  Study solar metal element fraction, resolve the conflict

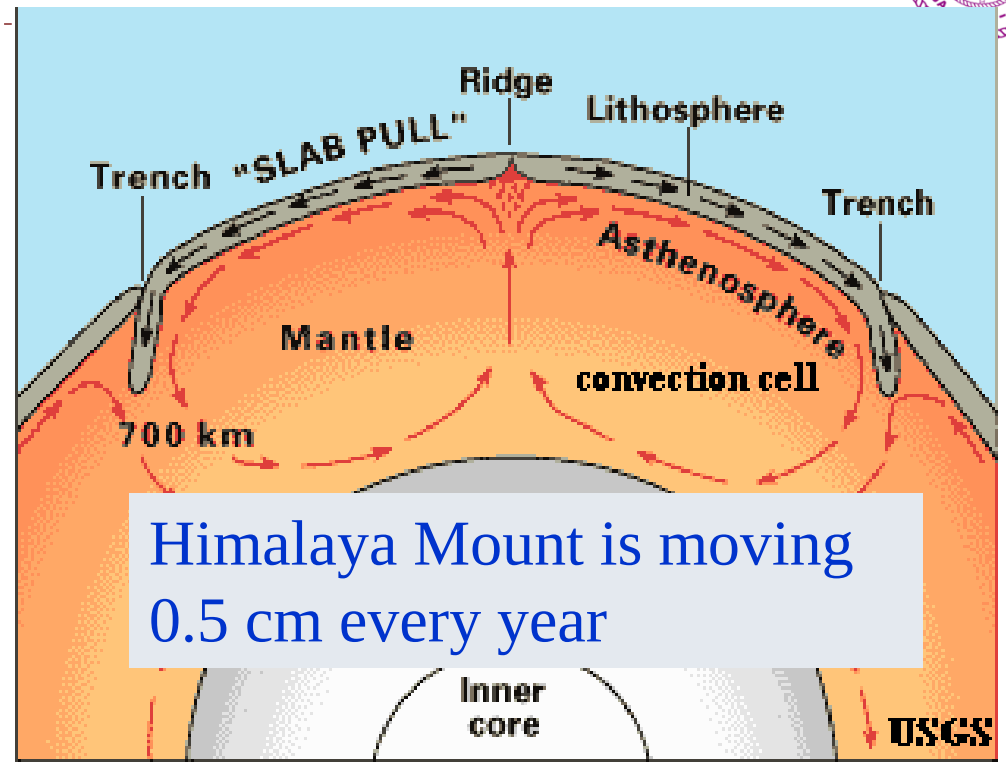
Neutrino oscillation

- Solar neutrino oscillation
  Transition from vacuum to matter oscillation
- Precise measurement and new physics

Geoneutrinos

Diving power

- Initial gravity
- Nuclear power, U, Th, K decay



Knowledge:

- Global heat measurement 47±3 TW
- Theoretical predictions:
  - Low range 10 TW
  - Middle range15-30 TW
  - High range 20 TW
- Geoneutrinos from U, Th: 10-30 TW

- Still consuming initial gravitational power
- Need more measurement of mantle neutrinos

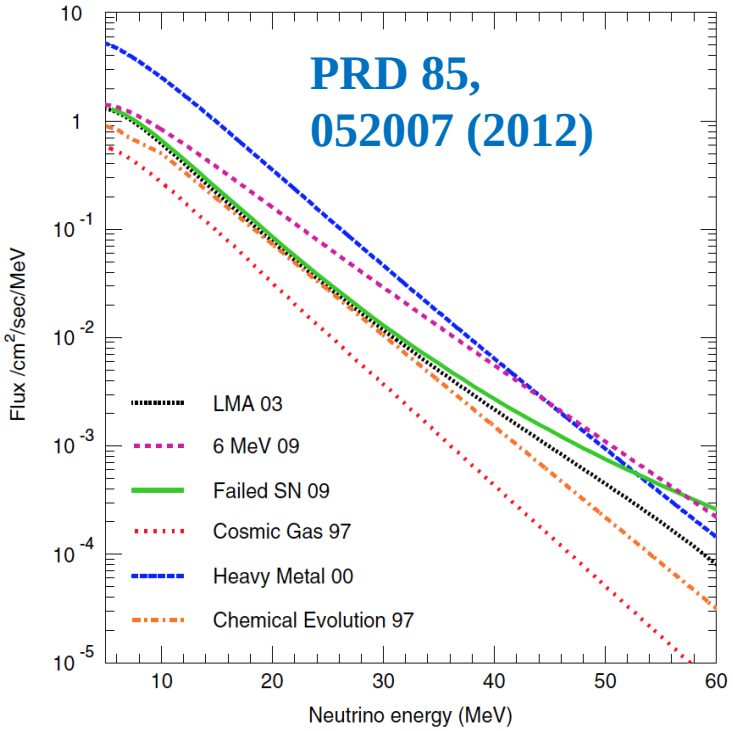
Supernova relic neutrino

$$\frac{d\phi(E)}{dE} = \int R_{\mathrm{ccSN}}(z)\frac{dN(E')}{dE'}(1+z)\left|\frac{dt}{dz}\right|dz$$

1. R_{ccSN} – Rate of core collapse supernova (optical observation)

2. dN/dE‘ – Neutrino energy spectrum (Supernova temperature)

3. Other constants: redshift



- SRN: A finger print of star formation rate and star evolution mechanism.

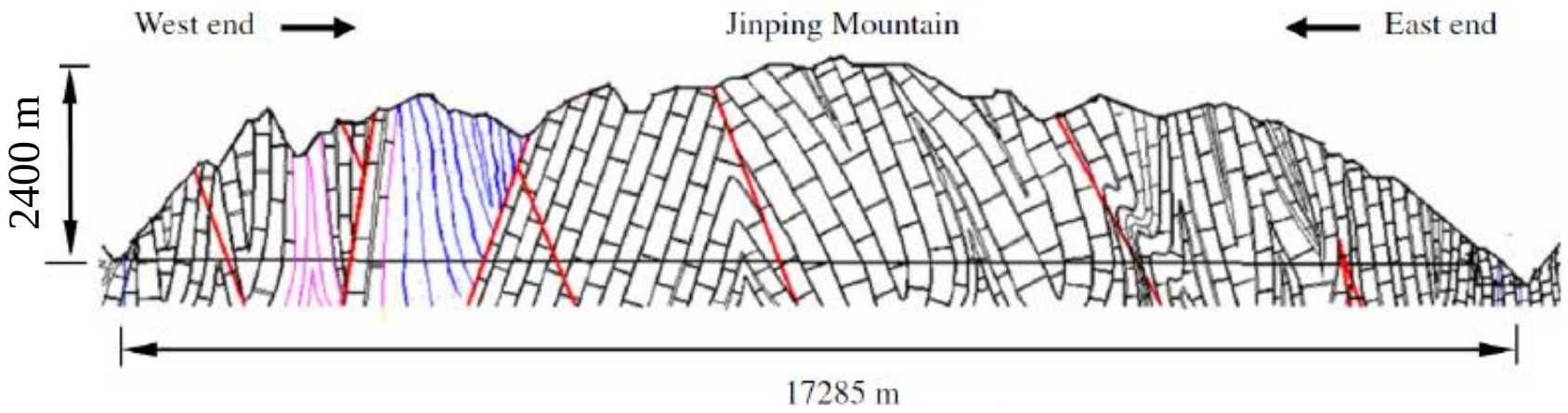
Jinping Laboratory

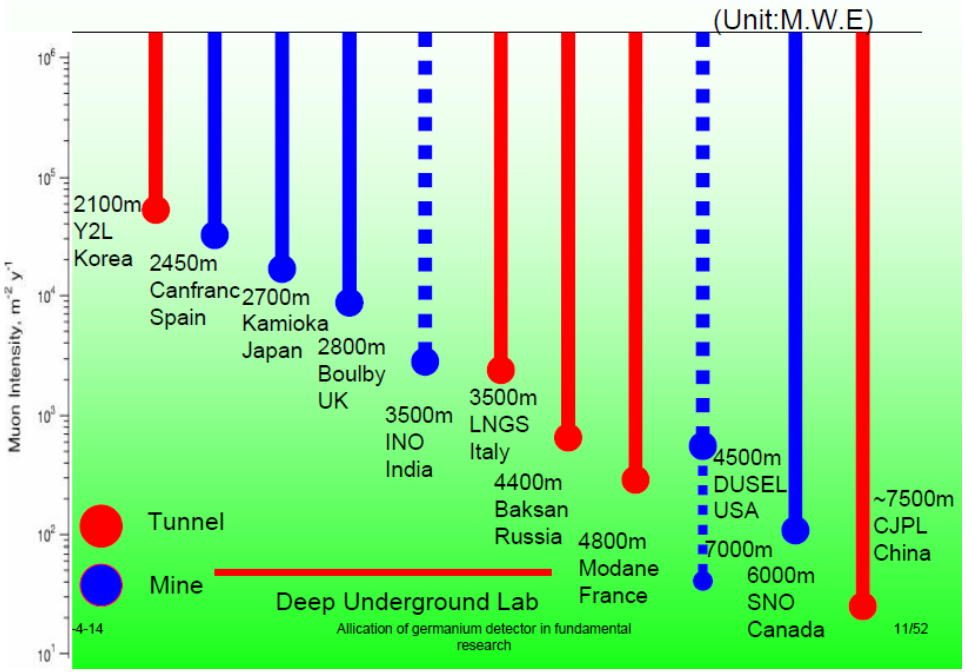
China Jinping Underground Laboratory

Flight: Beijing (Shanghai, Guangzhou) - Xichang

Car: Xichang - Jinping (2 hours)

Depth and Muon Flux

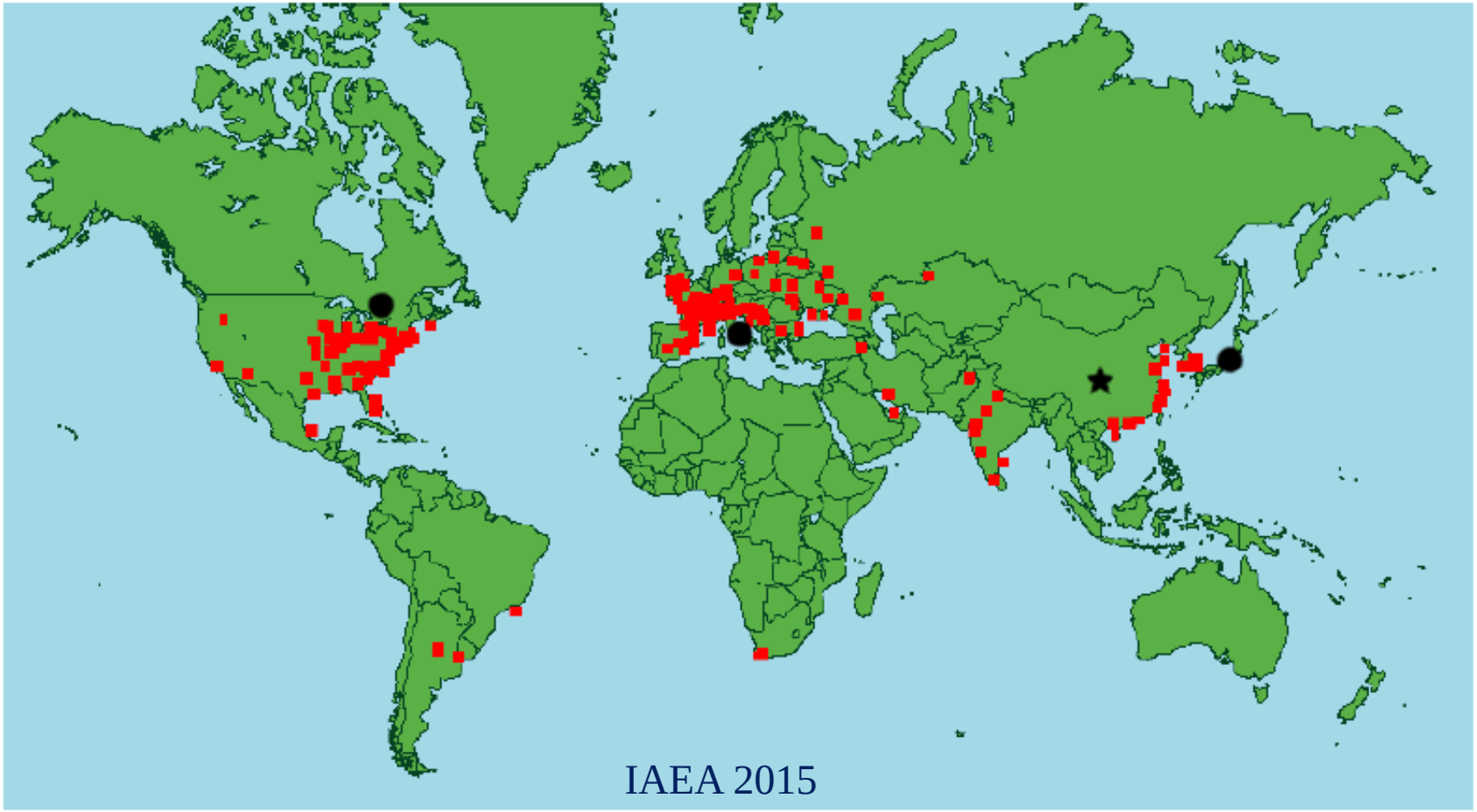




2400 m underground Muon and related background

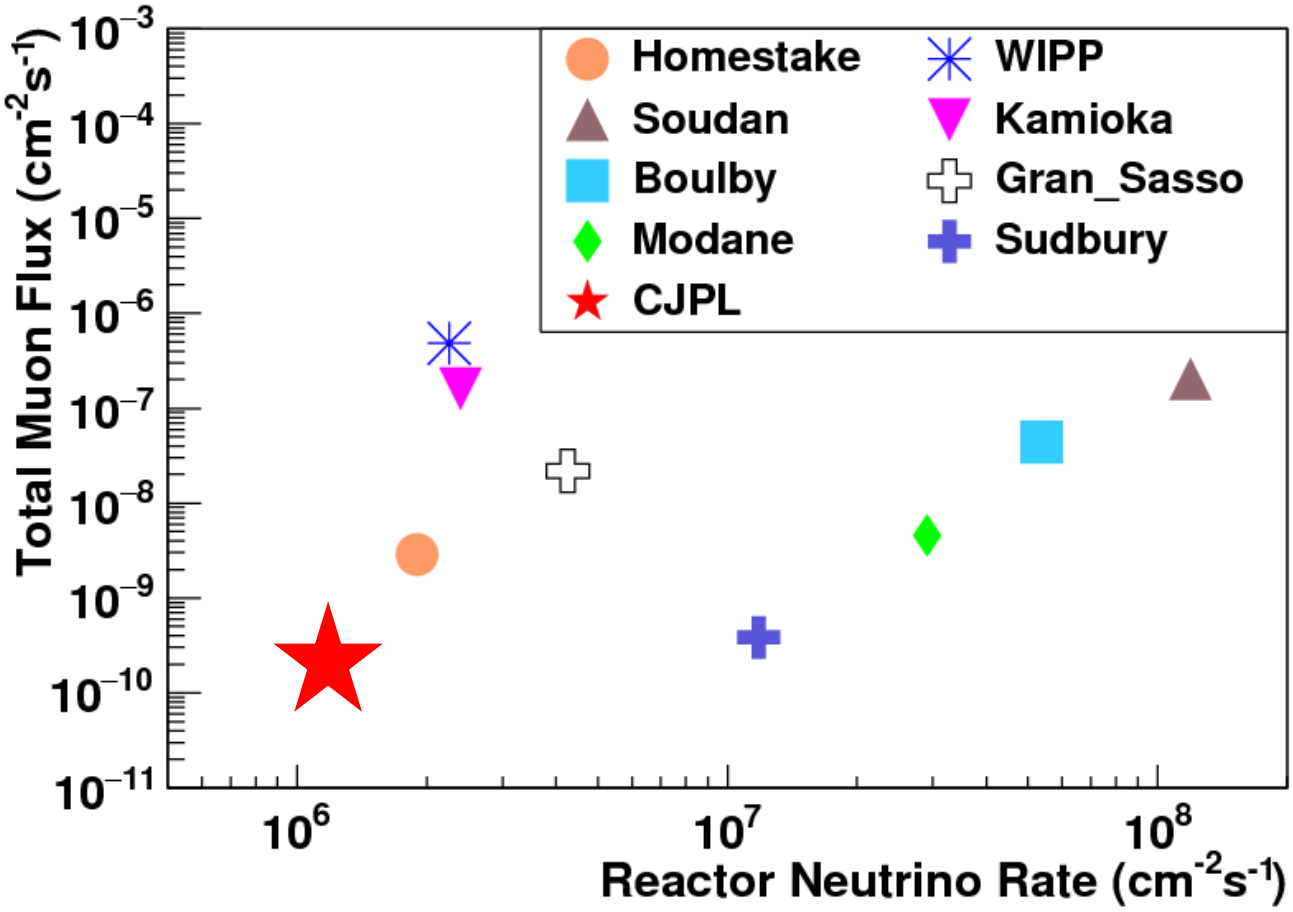
- 1/200 of LNGS
- 1/2 of SNOLAB

Reactor Neutrino Background

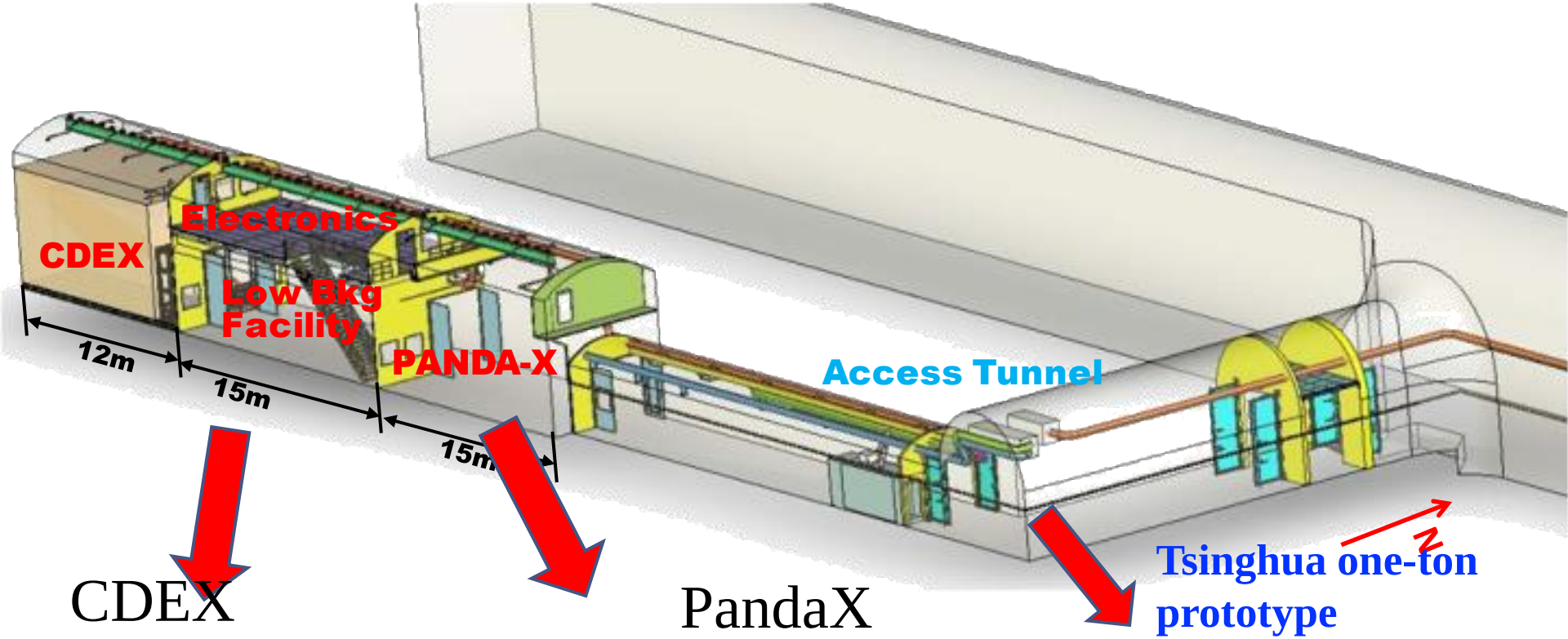


Closest reactor 1200 km

An ideal site for low background neutrino Exp.



CJPL-I status



CDEX

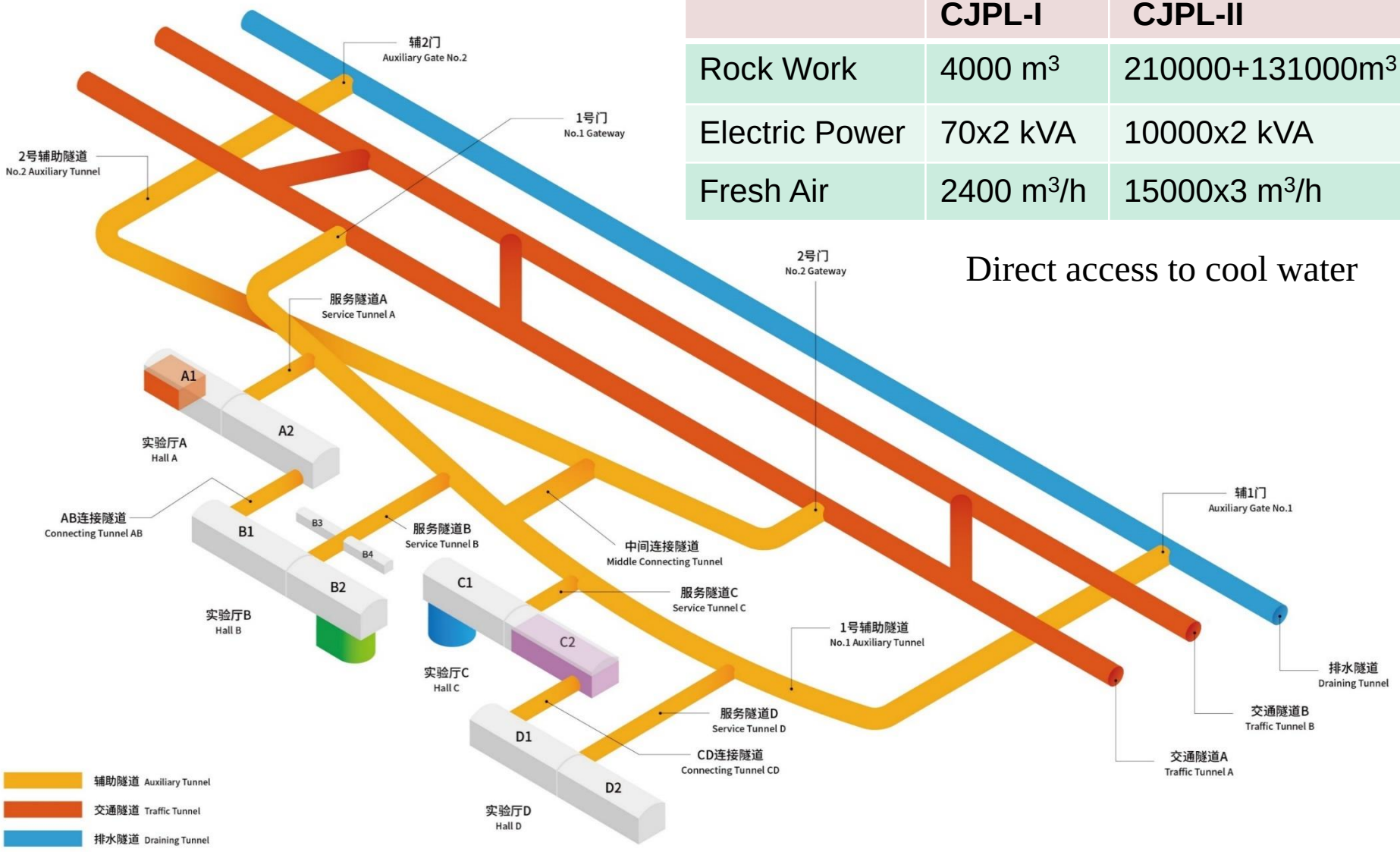
PandaX

Tsinghua one-ton prototype

CJPL-II Layout

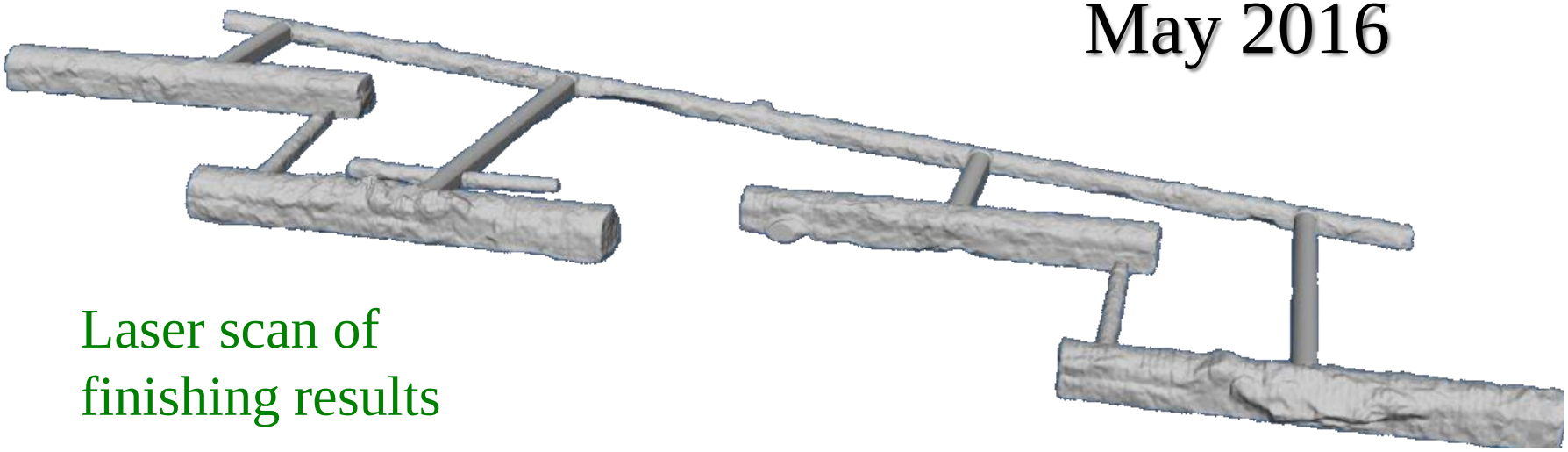
	CJPL-I	CJPL-II
Rock Work	4000 m^3	210000+131000m^3
Electric Power	70x2 kVA	10000x2 kVA
Fresh Air	2400 m^3/h	15000x3 m^3/h

Direct access to cool water



CJPL Current status

May 2016

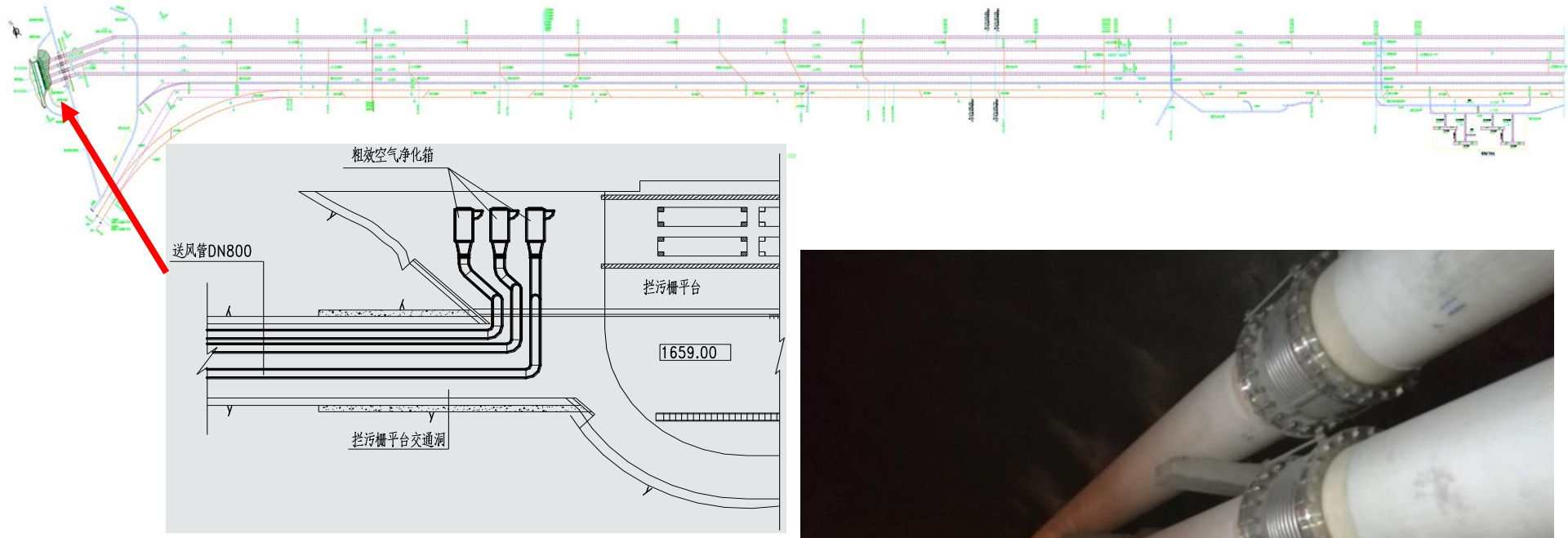


Laser scan of
finishing results

CDEX pit and
PandaX pit done

One hall
14 m x 120 m

Air system at CJPL-II



- Fresh air pipes: 9km Φ800 PE x3
- Main fan: 75kW x4
- Max. fresh air flux: 45000m^3/h
- Normal fresh air flux: 24000m^3/h
- Will work in Oct. 2017

Jinping Neutrino Experiment Proposal

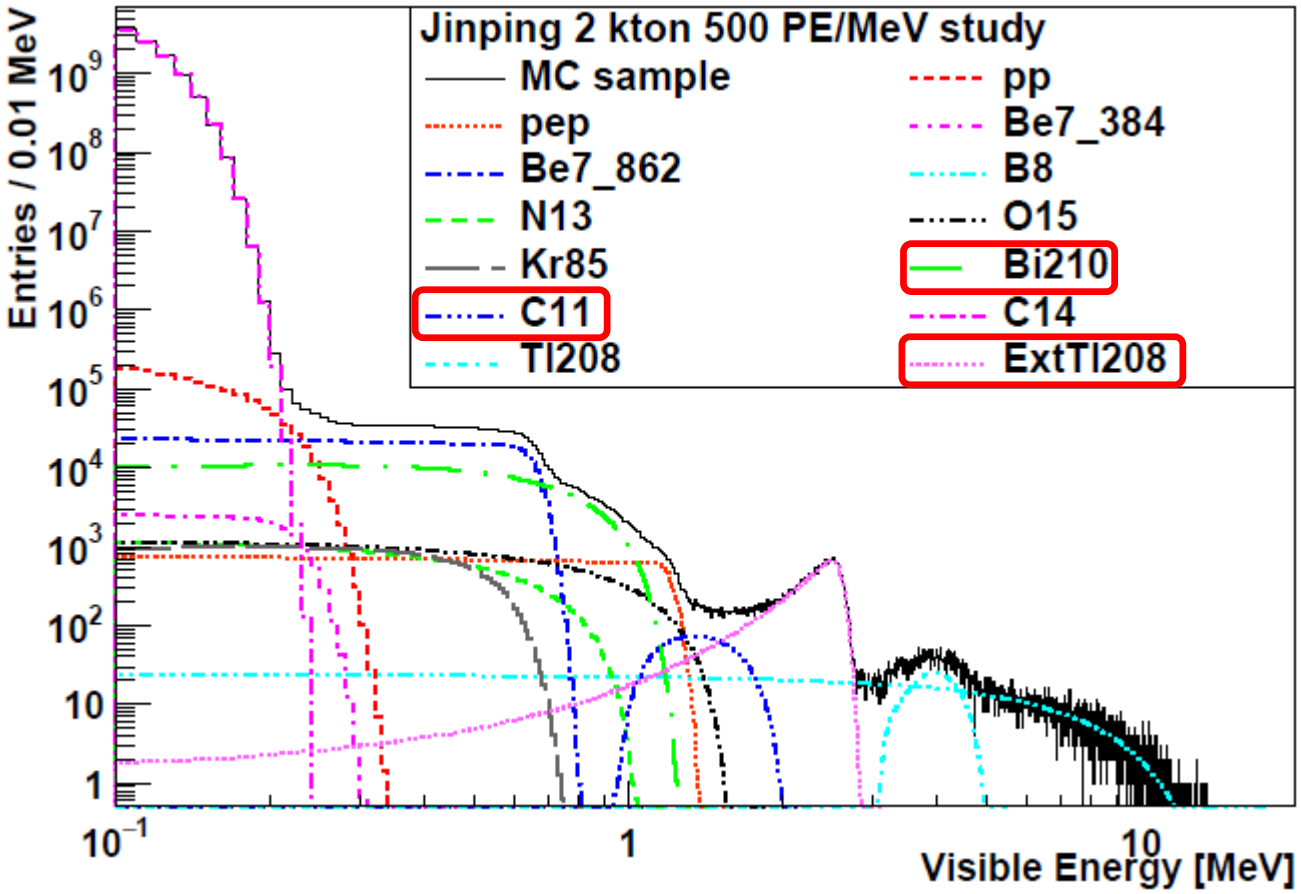
Jinping Neutrino Experiment Proposal

Chinese Physics C 41 (2017) 023002

With 2 kton fiducial mass for solar neutrino (equivalently 3 kton for geo and supernova relic neutrinos)

1. Discover CNO neutrinos
2. Solar ν oscillation
3. Precise geoneutrino flux measurement and U/Th ratio
4. Study SRN

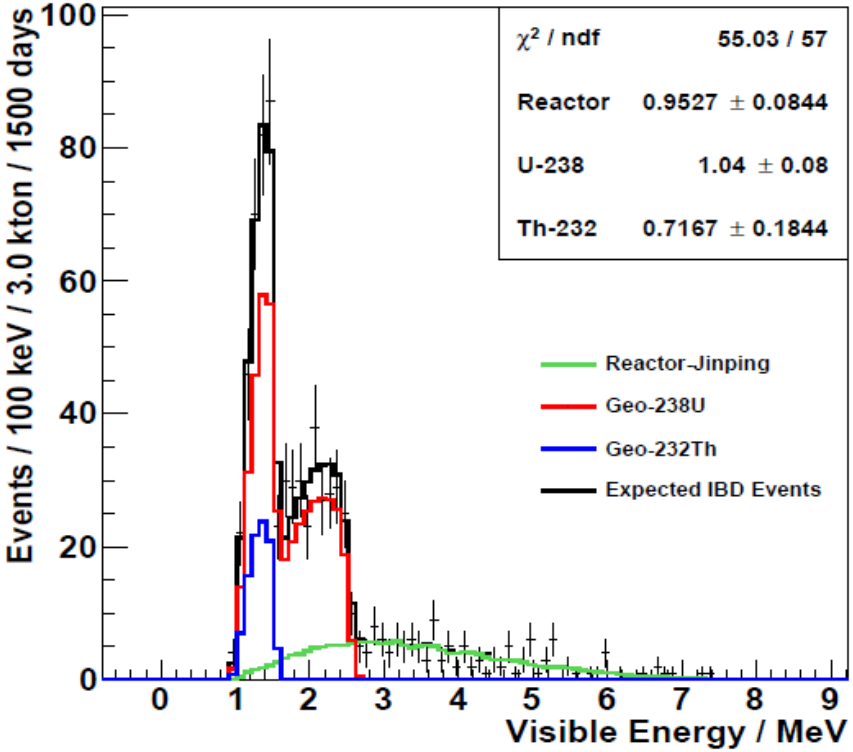
Solar Neutrinos

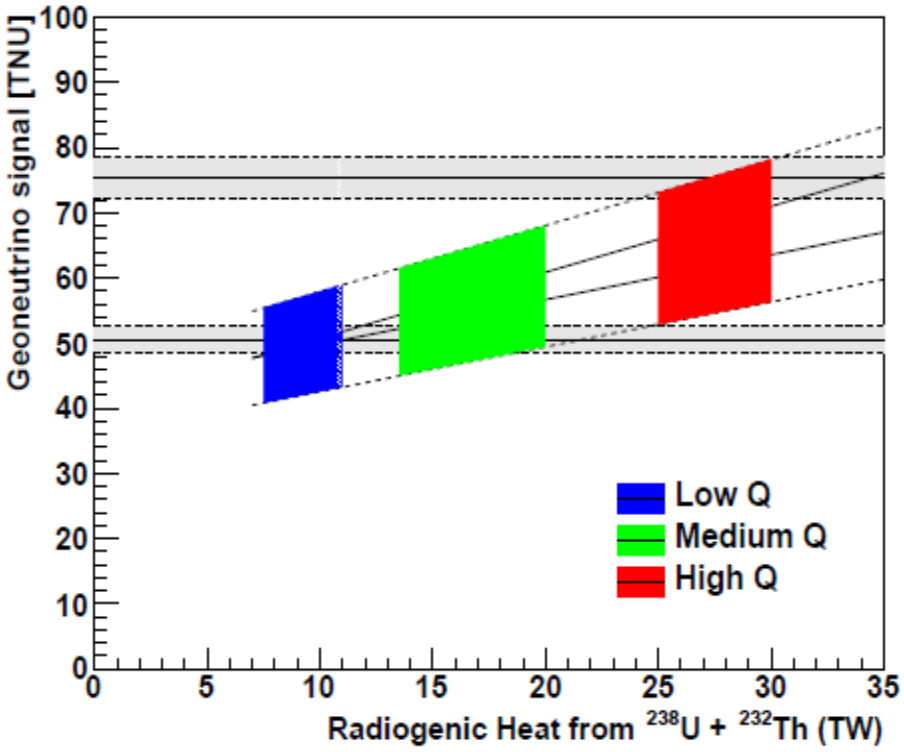


Simulation study with Borexino and Jinping assumptions.

O-15 precision 10%, constrain oscillation upturn

Geoneutrinos



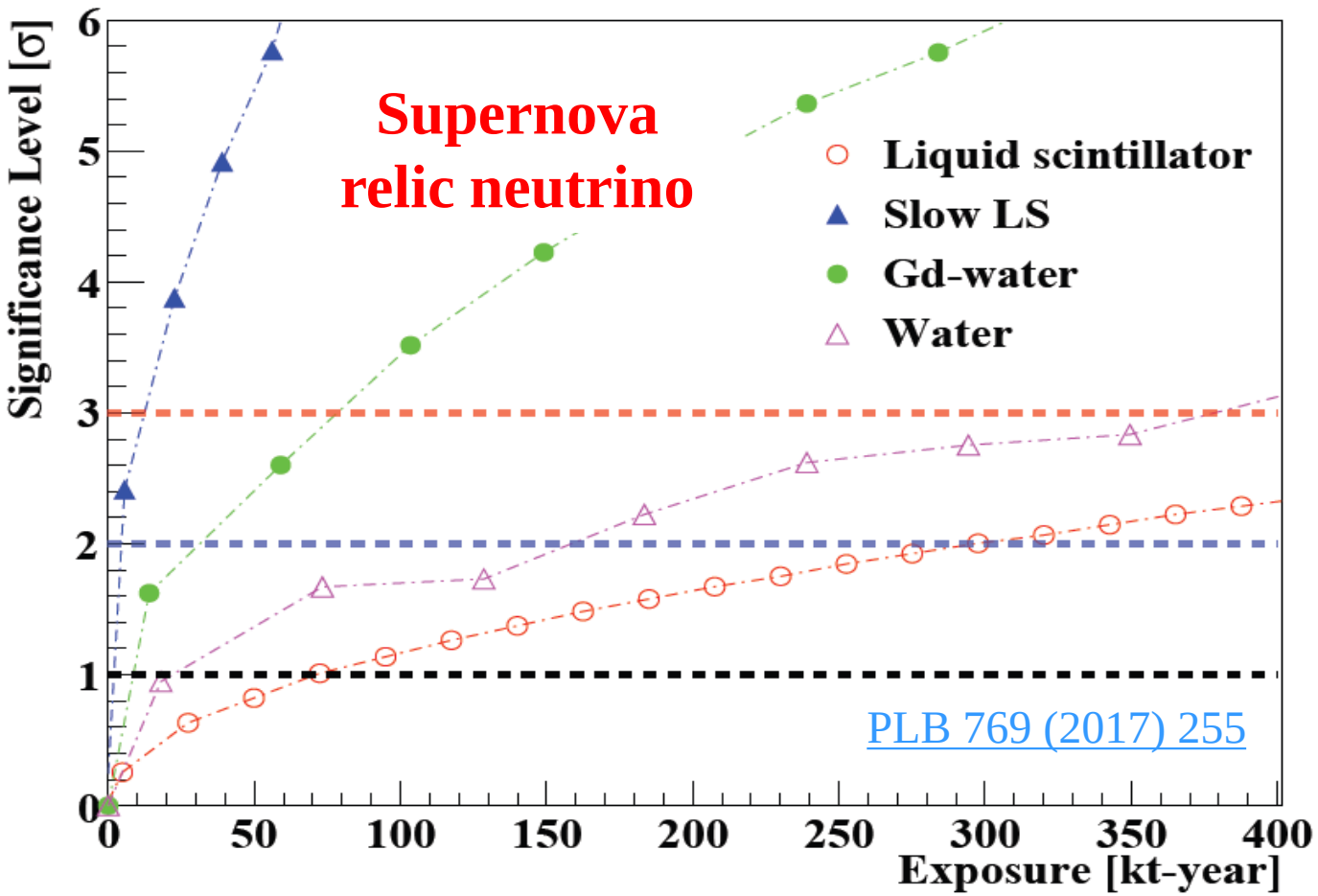


- U geoneutrino spectrum
- Th geoneutrino spectrum
- Th/U ratio ~ 10%
- Geo-reactor

- Address mantel contribution
- Geoneutrino flux prediction at Jinping

Sci. Rep. 6, 33034 (2016)

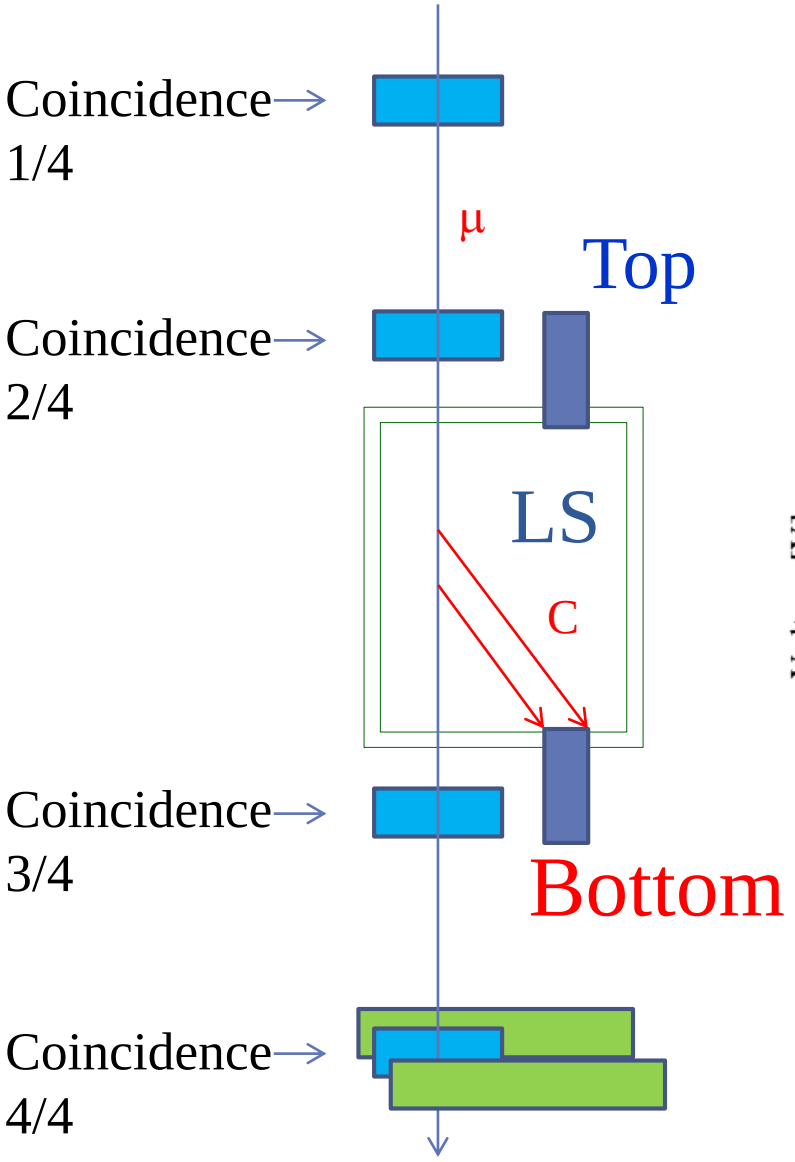
Expected sensitivity for SRN with Slow LS



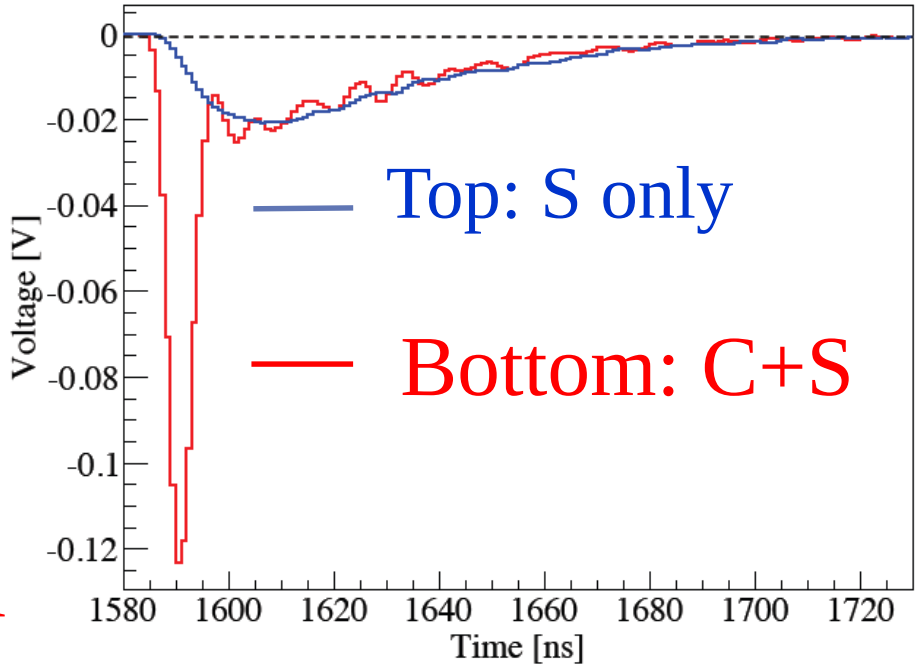
- 15 kton-year for a discovery with Slow LS
- The PSD in LS is not included here.

R&D Effort

Slow liquid scintillator

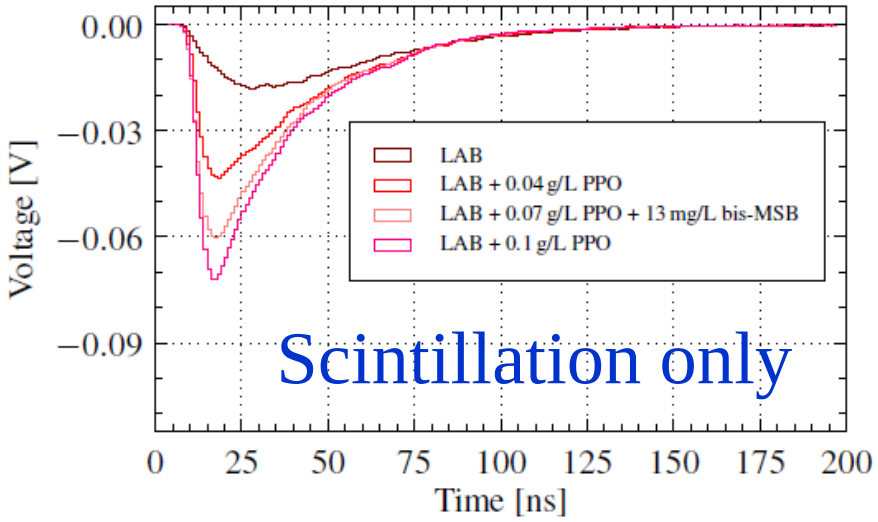


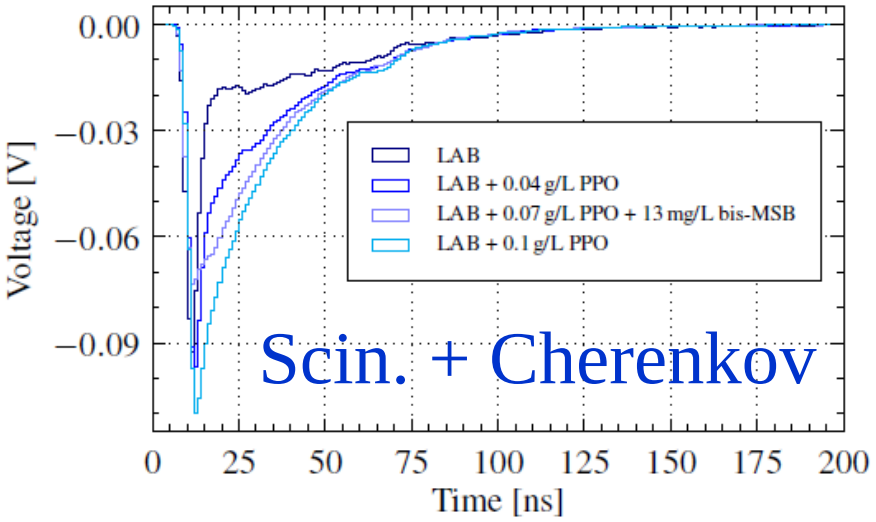
Waveforms of top and bottom PMTs in LAB

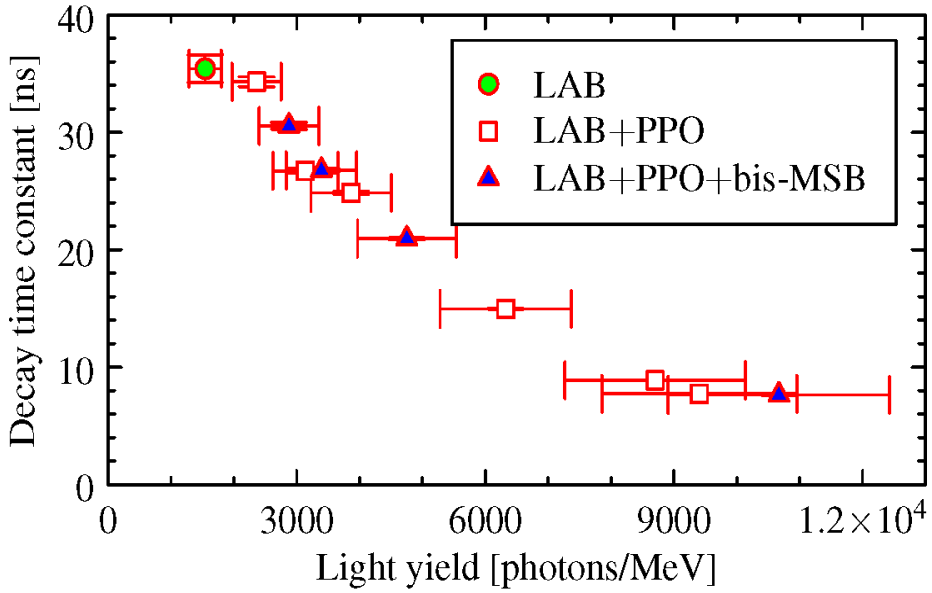


Nucl. Instrum. Methods Phys. Res. A 830 (2016) 303

Time and light yield scan



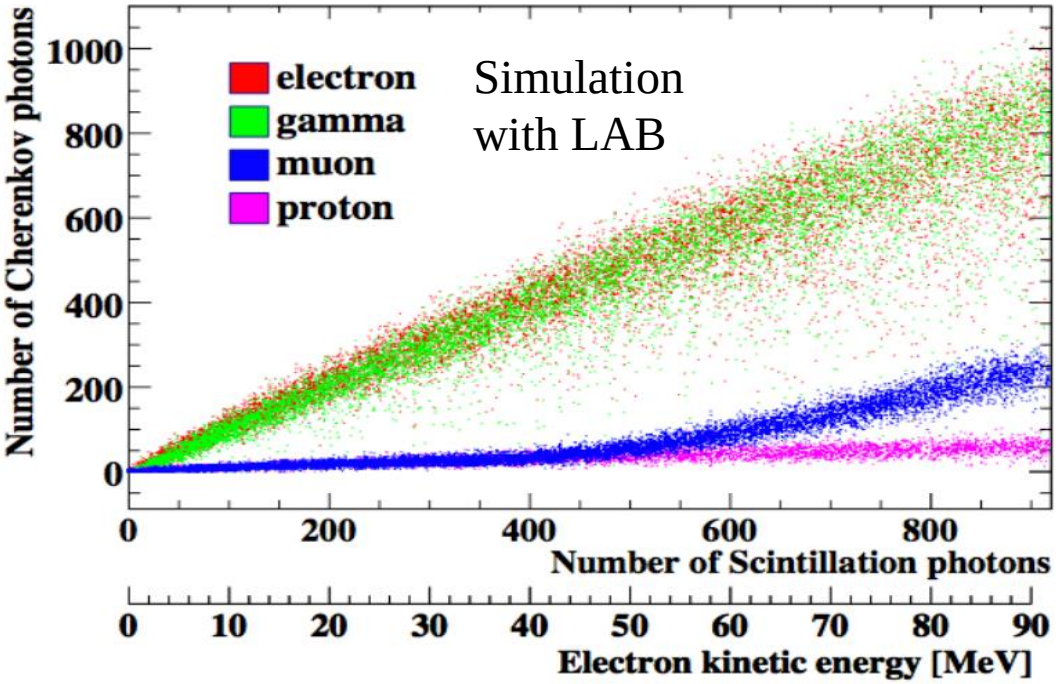




- Distinguish Cherenkov and scintillation light
- Reasonable light yield

arXiv:1708.07781

Liquid Cherenkov Scintillator (More)

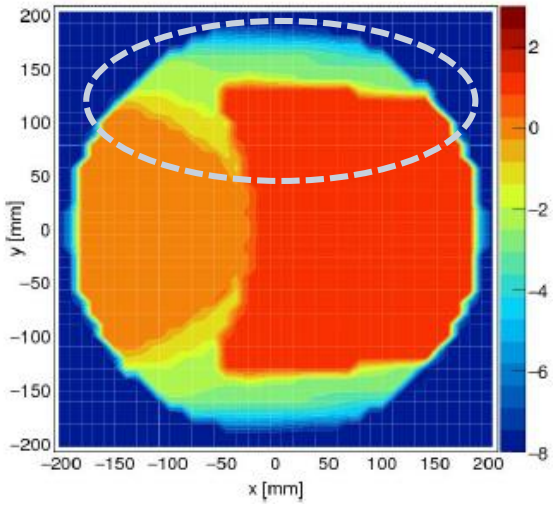


- Directionality (> 5MeV)
- Particle identification (mainly for electron, muon, proton, minor effect for gamma and positron)

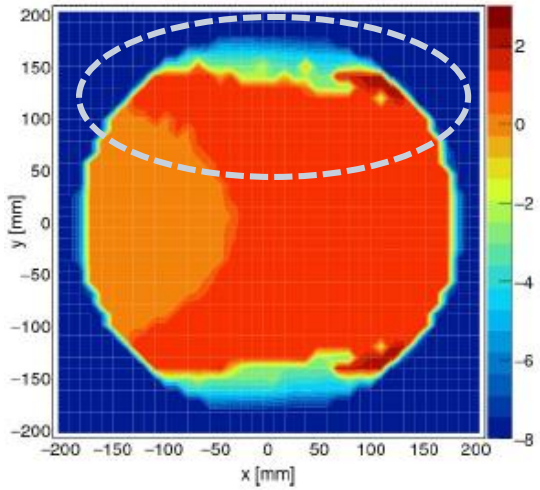
Use 3400 photon/MeV for estimation:
3400 x 100% (coverage) x 30% (QE) x 60% (attenuation) = 612 PE/MeV
Good for both solar, geo and SRN detection

Wide field-of-view and high-efficiency light concentrator

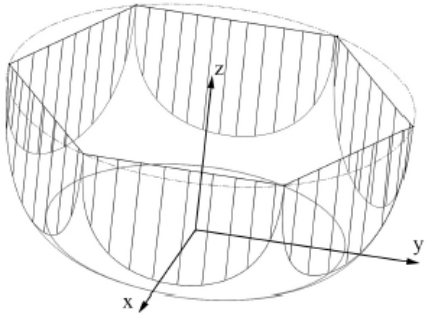
- Solar neutrino physics need high light yield.
- We add two more ideas to the String Method
  1. Consider the 3D geometry profile of PMT

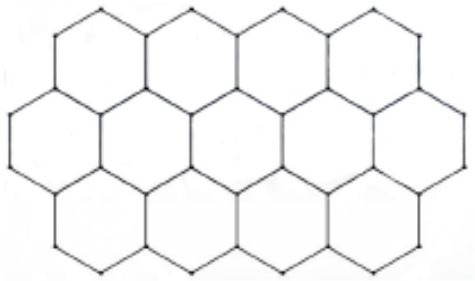


More light accepted

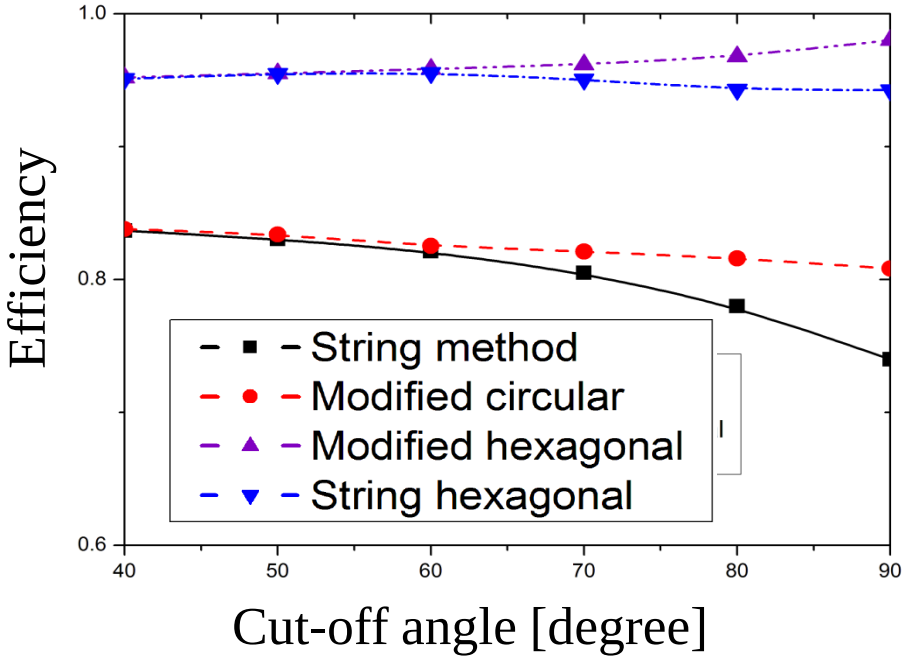


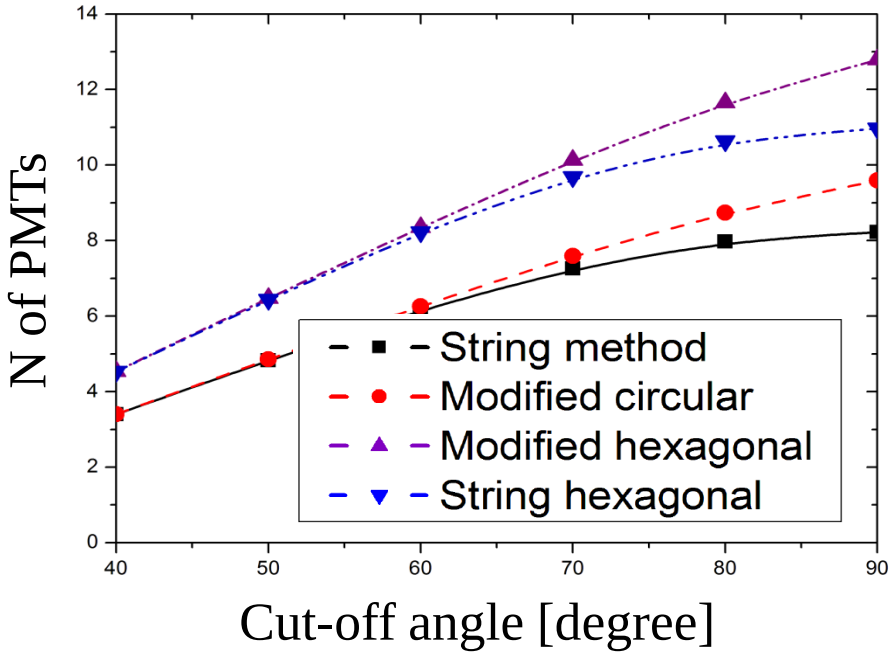
  2. Hexagonal opening





Geometry acceptance and numbers



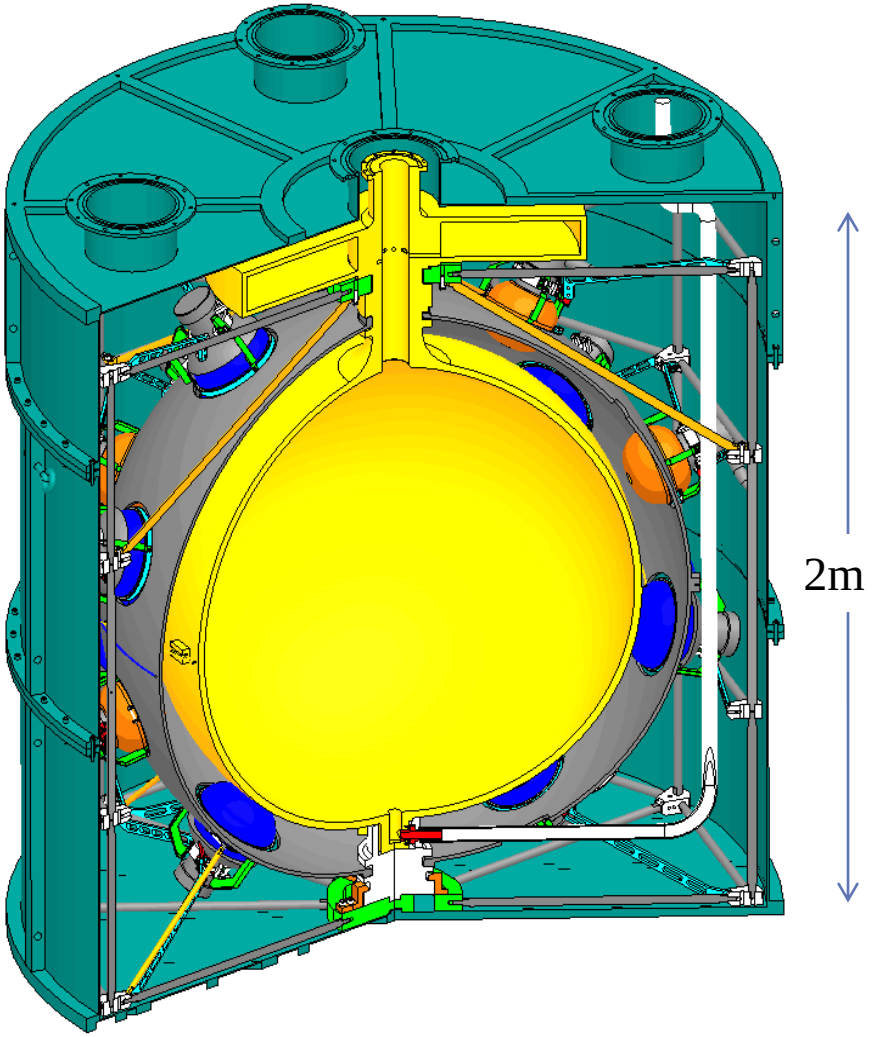


90° Cut-off	Photo cathode Coverage	Collection efficiency	N of PMT (m^{-2})
No reflector	91%	100%	14.73
Modified hexagonal	100%	97%	11.65

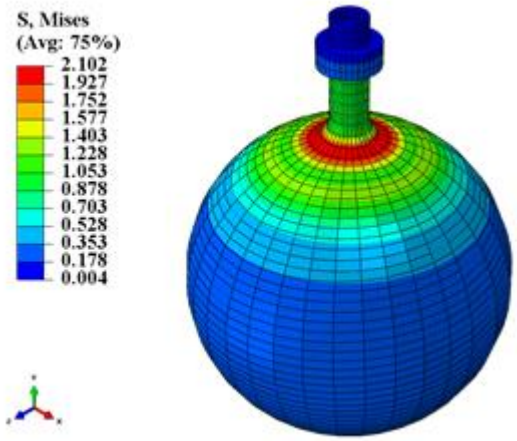
A 1-ton prototype at Jinping

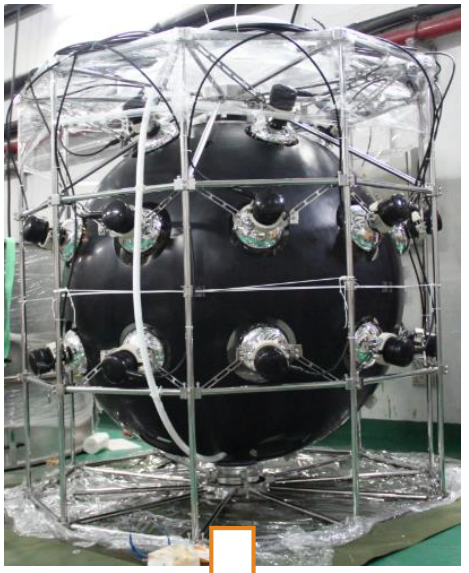
1. **Measure fast neutron background**
2. **Test detection material: water, LS, and slow LS**
3. **A low bkg. facility**
4. **Reconstruction**

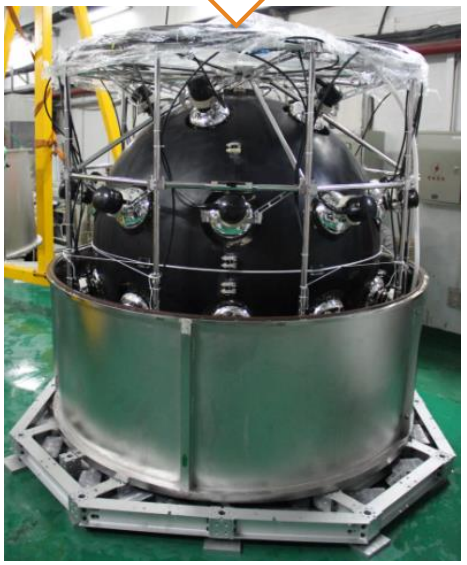
30 8" PMTs
FADC 10 bit 1GS/s
Transparent acrylic vessel
=> Inside: 1ton for LS
=> Water outside
Whole detector: lead shielding



Design and installation



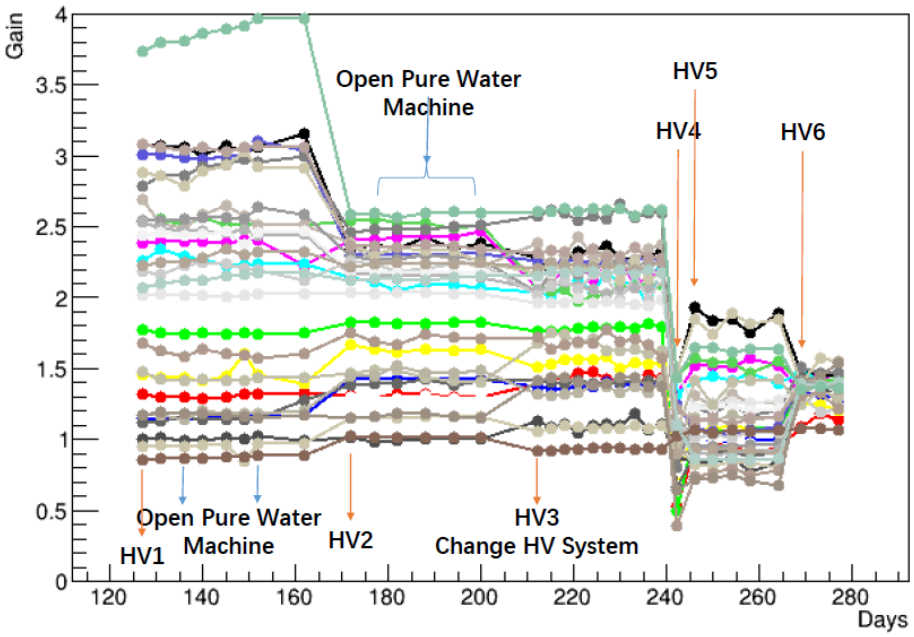


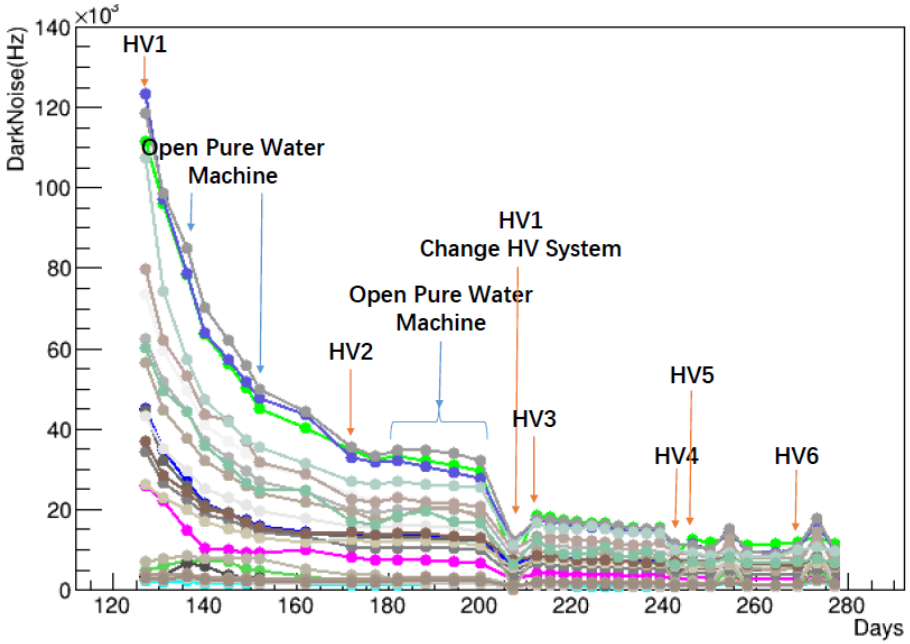


A 1-ton prototype at Jinping

Since May 10, 2017, taking data with pure water inside.
Now taking data with a type of liquid scintillator.

One-ton prototype calibration





PMT gains are set uniformly

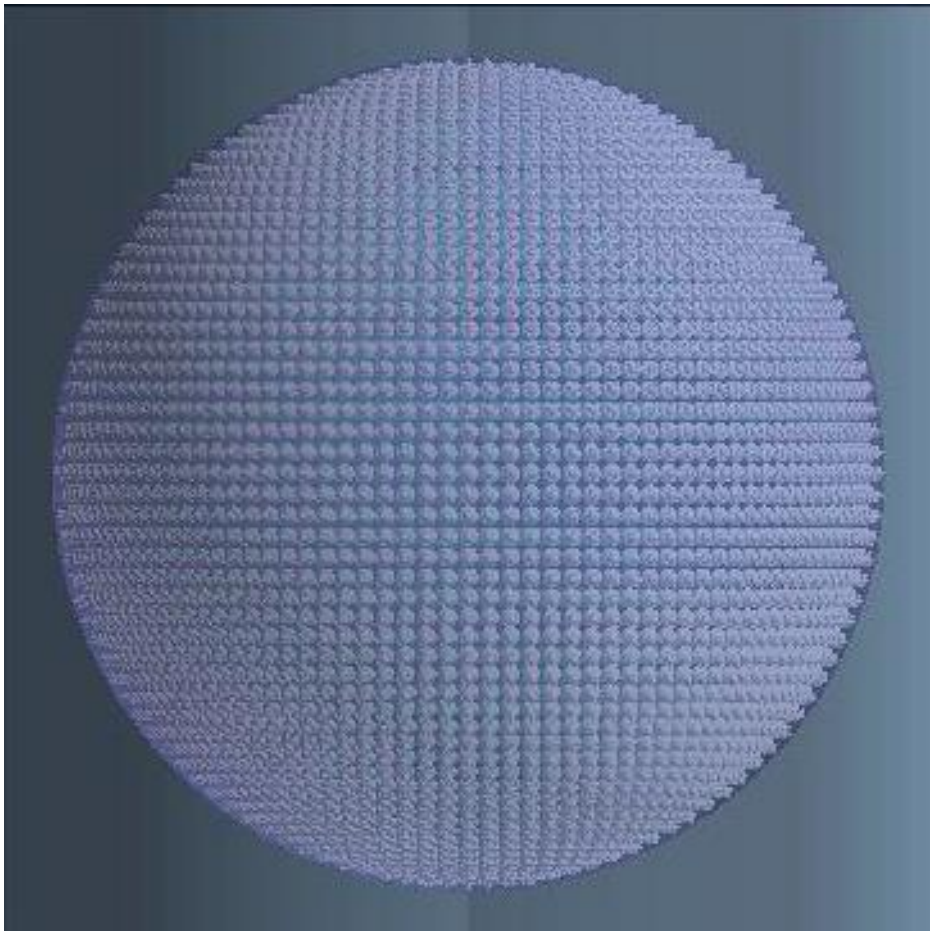
PMT dark noise has settled down to 5k-10k

Doing studies about underground background and Slow LS

Jinping simulation & analysis package

JSAP

1. **Comprehensive optical simulation**
2. **Flexible to different geometry setup**
3. **Waveform simulation**
4. **Flow style simulation G4->PMT->Elec-> Trigger (Not event by event)**
5. **Doing Slow LS study**
6. **Doing Detector Optimization**



Low background SST by smelting process

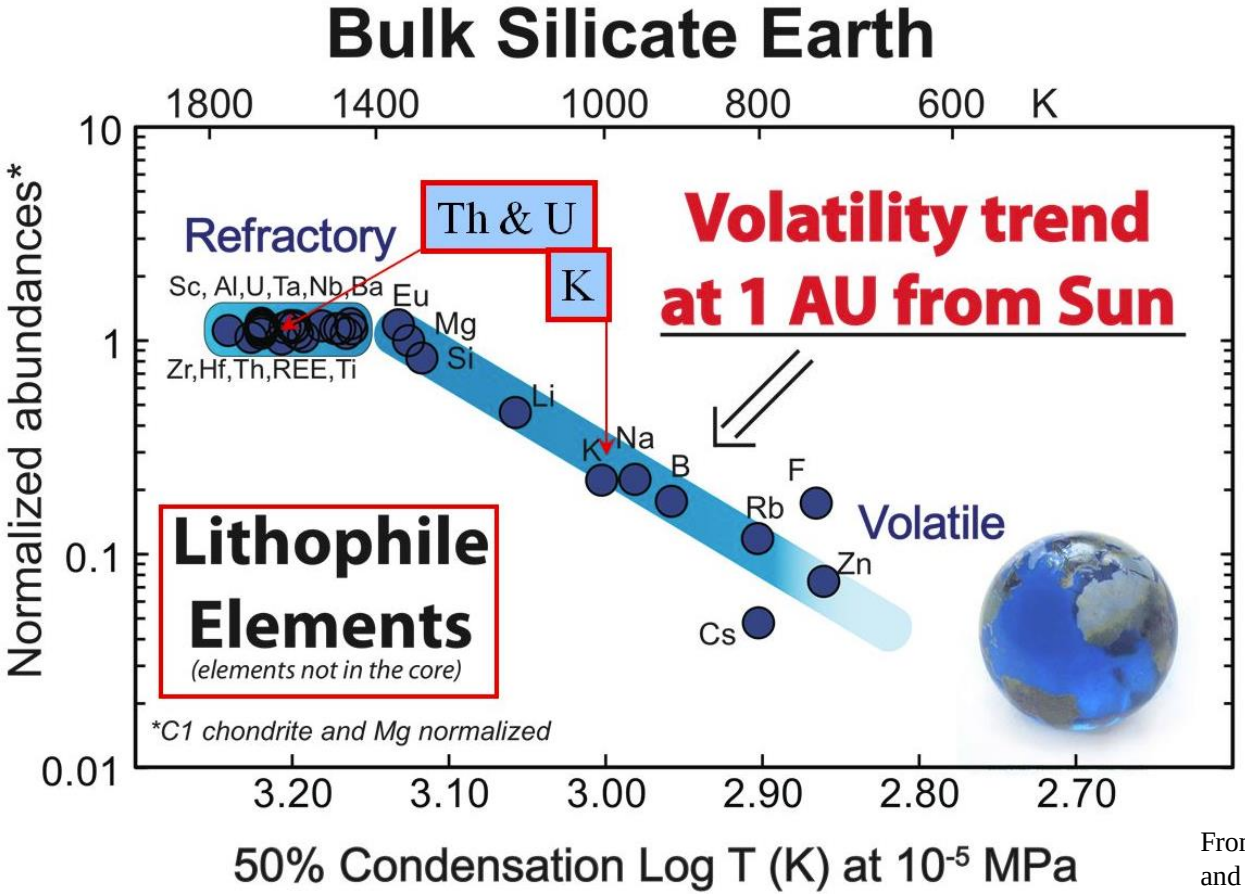
Analyzed by GDMS (1E-9 g/g), HPGe-groud (Bq/Kg), HPGe-Jinping (mBq/Kg)

1. C, Si, MgO sand: have a significant radioactivity
2. S, P: harmful to SST
3. Mn is not 100% necessary
4. Settle down on Fe, Cr, Ni (304L), Mo (316L)
5. Small impact from MgO crucible

mBq/kg	316L	Borexino	NEXT
U-238	~6	4.6±0.9	32±9
Th-232	~5	11.4±1.2	1.9±0.2
K-40	~11	<14	3.2±0.7
Co-60	~2	6±1	1.8±0.1

More wild thought on slow liquid scintillator

Volatile elements on the Earth

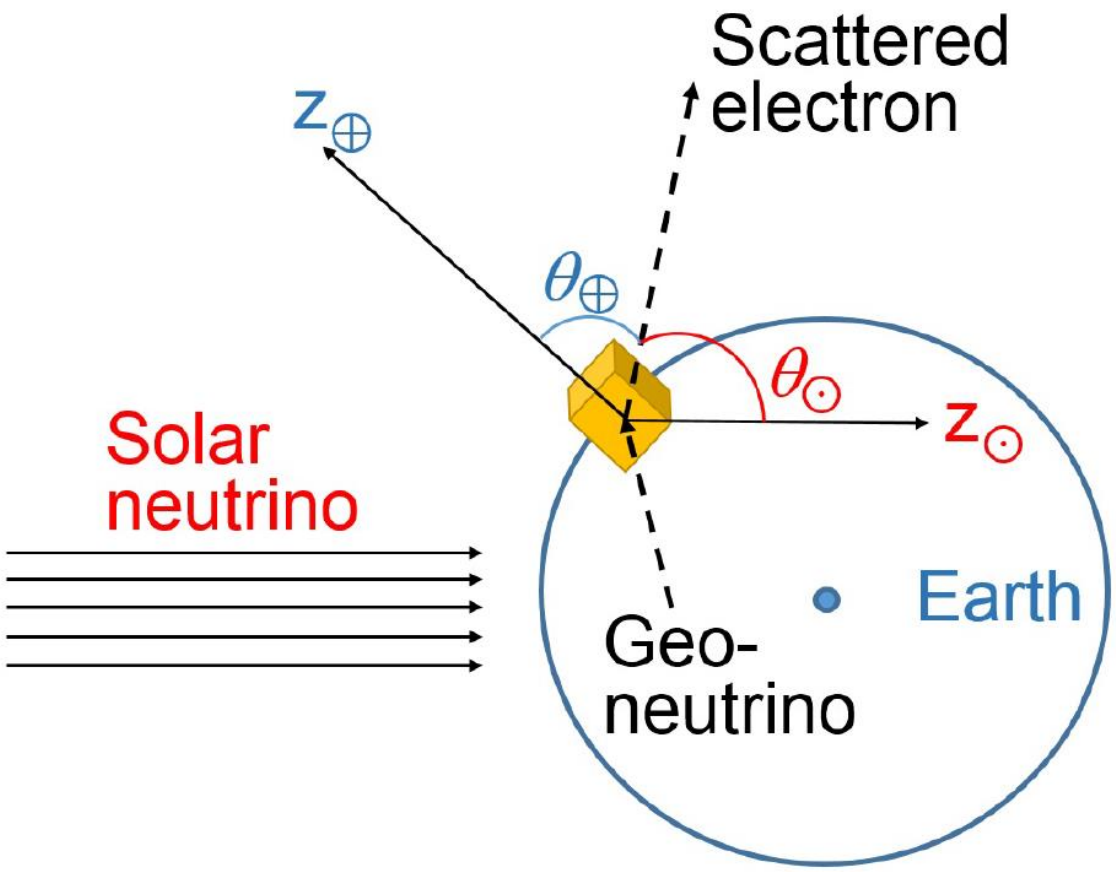


From McDonald and Sun 1995

- Measure U, Th can fix refractory elements
- Need measurement of K40 geoneutrinos to finish the picture for volatile elements

Reveal K-40 and mantle geo neutrinos

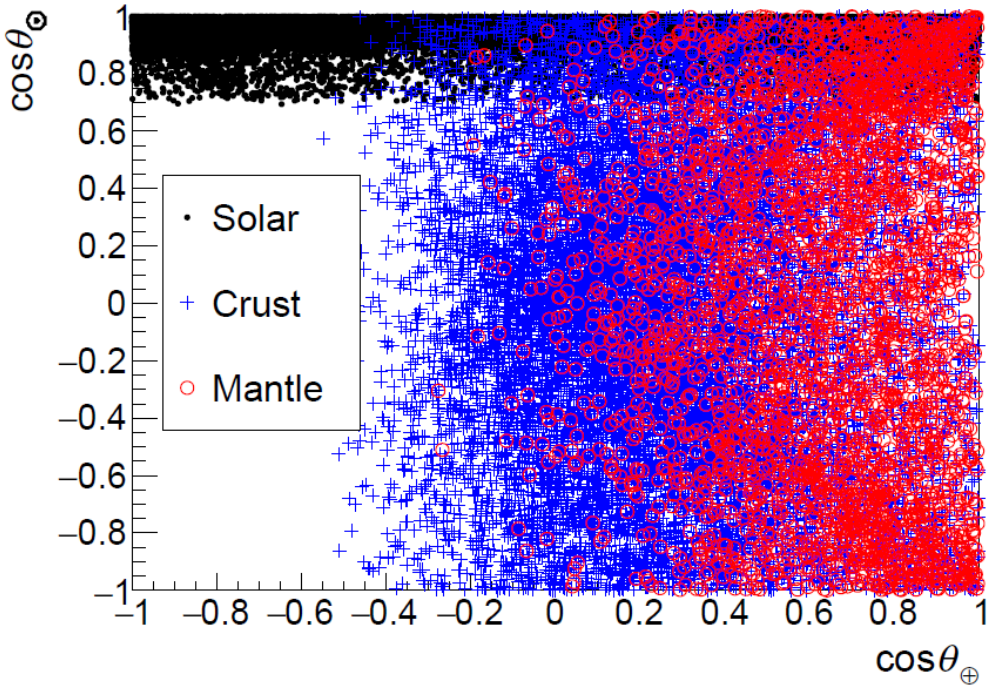
Measure geoneutrino electron scattering:



arXiv:1709.03743

Suppression of solar neutrino background

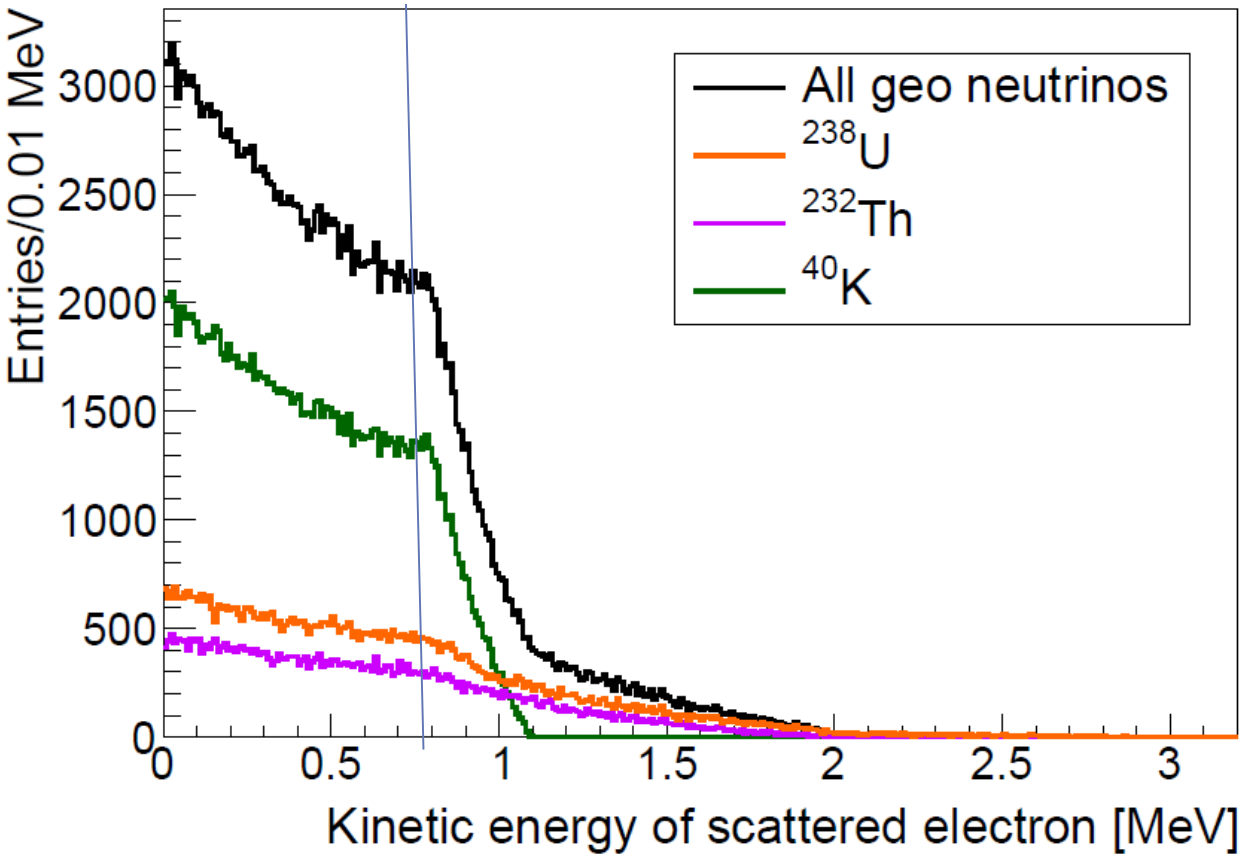
With Te>0.8, solar and geo neutrinos are in different groups.



Statistics in a 2kton detector with Te>0.8

	All geoneutrinos	^{40}K	Mantle
$\cos\theta_\odot$ <0	189	64	32
$\cos\theta_\odot$ <0.5	291	97	46

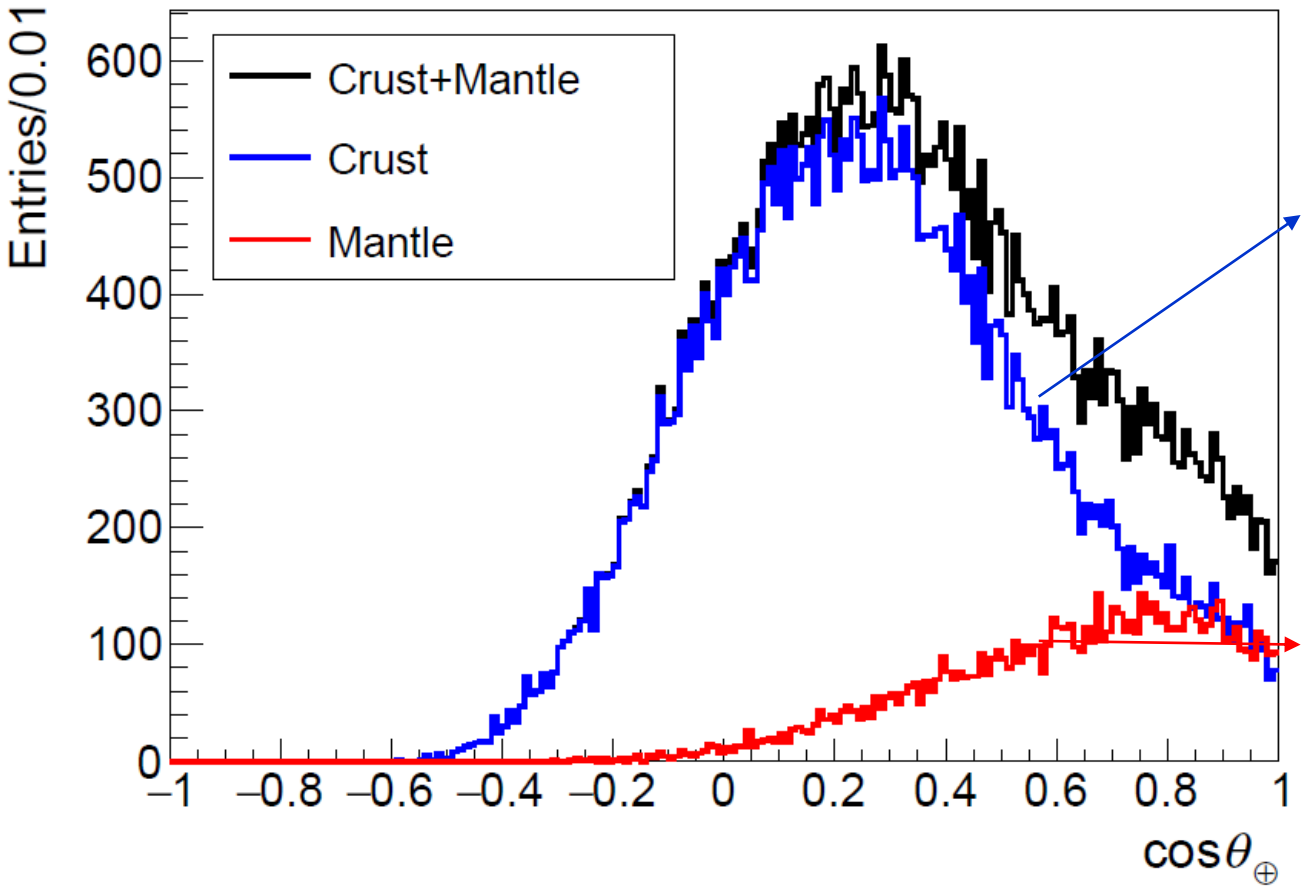
Distinguish K-40 neutrinos



At 0.8 MeV, K-40 dominant, distinguishable structure

With LAPPD, it works without any question.

Mantle and crust neutrinos



Distribution determined by crust shell structure

Mantle structure, from underneath

Distinguish mantle from crust components by spectrum fitting.

Next step

CJPL in the 13th Five Year Plan

- **CJPL has been listed into the 13th five-year national plan for major science and technology infrastructure programs**

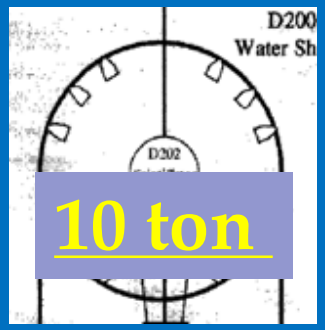
国家重大科技基础设施建设“十三五”规划

（三）极深地下极低辐射本底前沿物理实验设施。

- **Statements from the CJPL international advisory committee**
  - **Build a strong collaboration and formulate an optimal strategy for advancing to a large, deep and unique observatory for low-energy neutrinos.**

Workshop for Jinping Neutrino Experiment

1. **2015, 2017 two international workshops**
2. **Participants from:**
   Tsinghua, SYSU, Queen's University, UCAS, Guangxi University, Shandong University, BNL, University of Maryland, Technische Universität Dresden, Mainz University, Charles University, University of Michigan, Tohoku University, Nanjing University, Wuhan University



2025, initial physics goals

18′-20′: TDR

20: kiloton detectors' construction

16′-18′: CDR

17-18: 10-ton Prototype, Slow LS and low bkg. Tech

14′-15′: LOI

16: 1 ton Prototype

14-15: 20 L Prototype

14-15: Physics Sensitivity, Baseline parameter

Conclusion

- Basic questions for solar, geo, and supernova relic neutrino detections are unsolved.
- CJPL is ideal for these studies. Jinping Neutrino Experiment proposal
- Many R&D efforts: Reflector, low background SST, 1-ton prototype, liquid Cherenkov scintillator (acrylic strength, Electro-magnetic function, etc. not mentioned
- More thoughts on SRN and geo neutrinos
- A 10-ton prototype is in plan

More details can be found at http://jinping.hep.tsinghua.edu.cn/

Thank you for your attention.